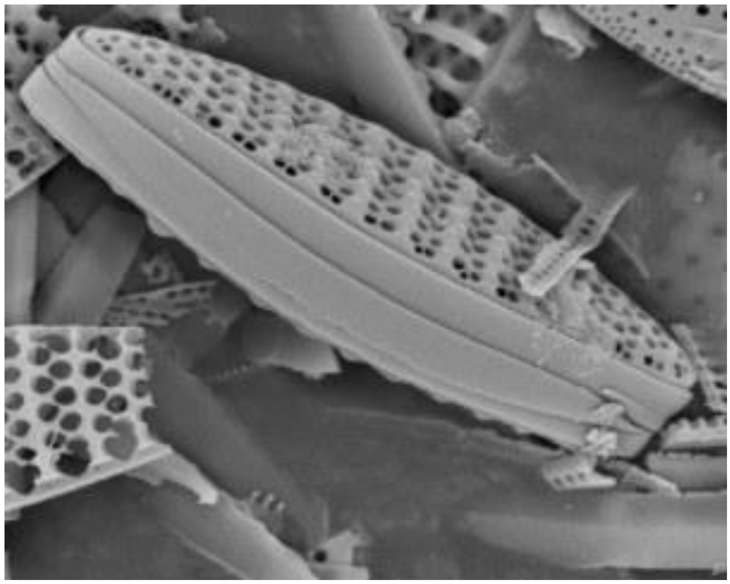
SCIENCE FOCUS: SOUTHERN OCEAN PHYTOPLANKTON

SOIREE: A Phytoplankton Party in the Southern Ocean



Electron microphotograph of the diatom *Fragilariopsis kerguelensis.* Photograph courtesy of Ivo Grigorov.

In the late 1980s, chemical oceanographers began to examine data that indicated that iron might be a limiting nutrient in vast areas of the ocean. The standard understanding before then had been that the growth of phytoplankton was limited by the availability of either dissolved nitrate or dissolved phosphate in seawater, and in some polar environments it might also be limited by dissolved silicon.

However, the late Dr. John Martin of Moss Landing Marine Laboratory, aided by his accurate determinations of iron concentrations in seawater, proposed that iron might be a limiting nutrient as well, and he also noted that the availability of iron might have significant climatic effects.

As there are no large continents that can supply iron, primarily due to dust aerosols, south of Australia, this area of the ocean has low iron concentrations. (Because Antarctica is ice-covered, it adds very little iron to the ocean's surface waters.) Thus, addition of iron should stimulate a phytoplankton bloom.

A quick chemical review: iron is only sparingly soluble in seawater, due to the formation of insoluble compounds with hydroxide ion (OH^-), which is prevalent at the normal pH range of the surface ocean (approximately pH 8). But iron is also pervasive in the global environment (and ships and wires and numerous other equipment are made of steel, which obviously contains iron), so accurately determining iron concentrations in seawater required scrupulously clean laboratory work.

Although Dr. John Martin became famous for proposing that iron acts as a limiting nutrient in oceanic waters, and also for theorizing that iron supply to the oceans could be related to climate change in Earth history, it was the accurate determination of the markedly low iron concentrations in seawater that allowed him to make these connections.

Dr. Martin even suggested that with a trainload of scrap iron, he could start a new Ice Age.

Initial experiments on board research vessels demonstrated that adding iron to seawater would enhance phytoplankton growth. But the real proof that iron was a limiting nutrient in the ocean required an in situ experiment: adding iron to seawater to see if phytoplankton growth in the ocean was enhanced. Two experiments near the Galapagos Islands in 1993 and 1995 demonstrated that phytoplankton growth was enhanced and also that the process could effect the concentration of dissolved carbon dioxide (CO_2) in seawater, which could in turn lead to a reduction of CO_2 in the atmosphere — the possible key to climate change.

The next logical step was to see how the process worked on a larger scale. That's what the Southern Ocean Iron Enrichment Experiment (SOIREE) was designed to determine. SOIREE took place in the Southern Ocean, approximately 2,000 km southwest of Tasmania. Working on the R/V *Tangaroa*, a research vessel operated by the National Institute of Water and Atmospheric Research (NIWA) of New Zealand, scientists dumped 8,663 kg of ferrous sulphate ($FeSO_4$) in acidified seawater into the surface ocean over an area of about 50 square kilometers. The first addition took place on February 9, 1999. Also in the mix was the compound sulfur hexafluoride (SF_6), a chemical tracer that allows the movement and dispersion of the iron-enriched water to be followed.

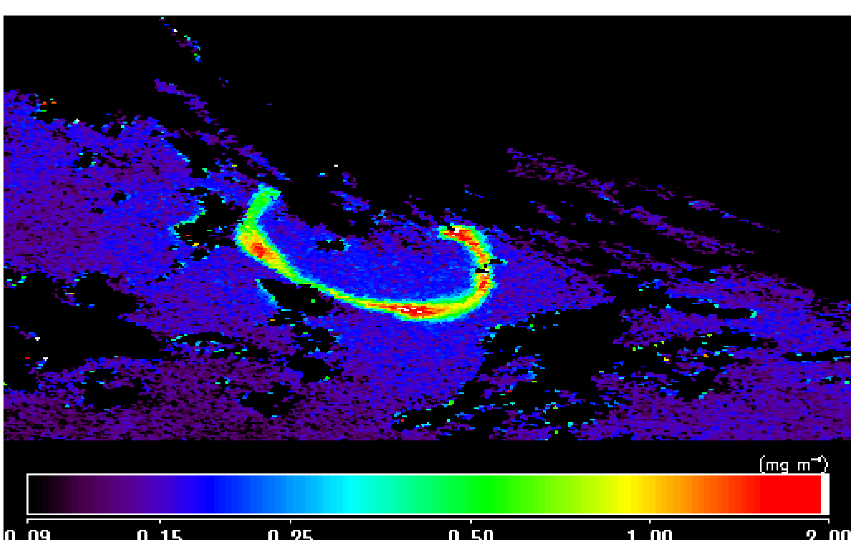
In about two days, the iron-enriched area had increased to over 100 square kilometers, and in 13 days it covered an area of over 200 square kilometers. In order to maintain increased iron concentrations, more solution was added on days 3, 5, and 7 of the experiment.

The R/V *Tangoroa*.

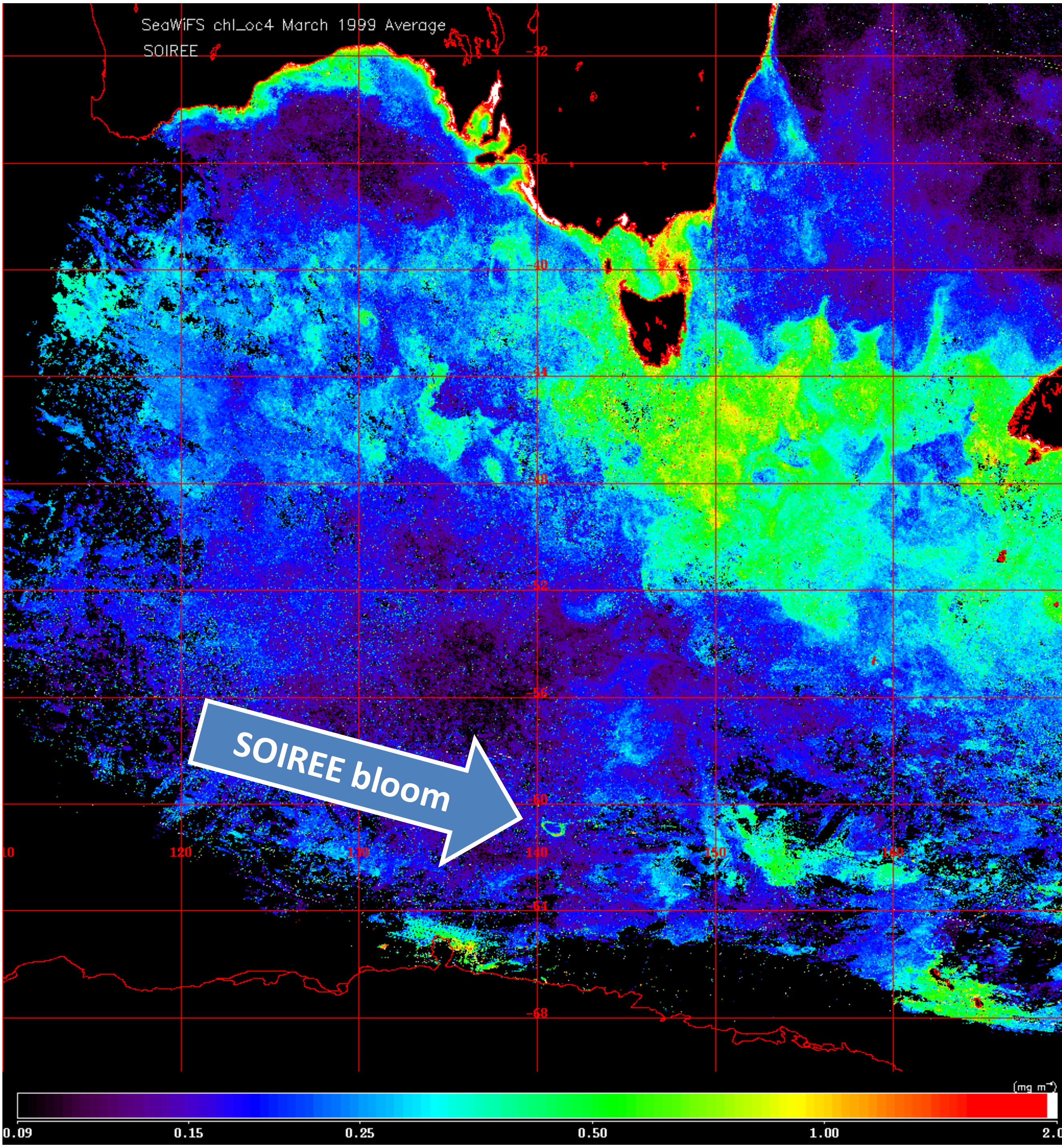
It took 5-7days for phytoplankton concentrations to respond to the iron fertilizer. Net algal growth more than doubled, the concentration of chlorophyll *a* increased by a factor of six, and algal carbon tripled. Researchers watched as the populations of various types of phytoplankton increased. The dominant diatom observed later in the study was *Fragilariopsis kerguelensis*. Increased uptake of dissolved silica and dissolved nitrate was noted. To summarize, the experiment worked, but ... (more on that later).

SeaWiFS provided several views of the evolving SOIREE phytoplankton bloom, and even allowed researchers continued observations of the bloom after the *Tangaroa* had left the area. The patch area expanded from a small, approximately circular region of chlorophyll to a larger area. Ocean circulation moved the patch in a semi-circular motion. In the high-resolution image below, the bloom can be seen as the bright semi-circular arc. The image is an 8-day composite, so it shows where the bloom was during the 8-day period of data acquisition by SeaWiFS.

8-day image of chlorophyll concentration in the SOIREE phytoplankton bloom.



Monthly SeaWiFS composite image for March in this region of the ocean. Additional movement of the SOIREE bloom can be perceived.



Preliminary analysis of SOIREE results

Optical microphotograph of *Fragilariopsis kerguelensis.*

Clearly, the phytoplankton productivity was dramatically increased. But one of the important facets of Martin's iron hypothesis as it relates to climate change is the importance of carbon export: after the carbon is produced, it has to leave the surface waters and be sequestered in the deep ocean in order for atmospheric CO_2 levels to eventually decrease. This process is called the *biological carbon pump*.

In the Galapagos, the biological carbon pump appeared to work more efficiently when iron was added, compared to the Southern Ocean; i.e., the ratio of carbon exported to the deep sea to the amount of carbon taken up by the organisms increased during iron enrichment. (This conclusion, however, was based on a small number of samples. See Bidigare et al. 1999.)

But in SOIREE, the response of the phytoplankton was quite a bit slower, so the biological pump never appeared to accelerate. The difference in temperature between the tropical waters near the Galapagos and the frigid Southern Ocean waters may have been a factor. Another tentative explanation for the SOIREE data is that two types of water—iron-fertilized water and high-nitrogen, low-chlorophyll (HNLC) water -- were being continuously exchanged at the surface. (This situation is analagous to a laboratory "chemostat", in which constant solution composition is maintained by continuous addition of chemicals.) In the case of SOIREE, dissolved silicate was added continuously, and a proportion of the iron-stimulated population of large diatoms was constantly lost from the system by advection (horizontal transport). Because mass phytoplankton sedimentation events are usually triggered by high cell abundances (which did not occur in SOIREE), algal growth in the iron-fertilized bloom was maintained without a corresponding export of carbon to the deep sea. Subsequent research will have to examine the question of carbon production and carbon export in iron-stimulated blooms.

We thank Dr. Philip W. Boyd for a review of this Science Focus! *article.*

Links

Iron Fertilization of the Ocean:

- http://www-formal.stanford.edu/jmc/progress/iron/iron.html
- The Iron Hypothesis
- Scientists Say Iron Particles Cut World Heat
- http://cafethorium.whoi.edu/Fe/1999-Annualreport.html

Fragilariopsis kerguelensis:

http://www2.npolar.no/~simon/f__kerguelensis.htm

References

- "A mesoscale phytoplankton bloom in the polar Southern Ocean stimulated by iron fertilization", Philip W. Boyd, Andrew J. Watson, Cliff S. Law, Edward R. Abraham, Thomas Trull, Rob Murdoch, Dorothee C.E. Bakker, Andrew R. Bowie, K.O. Buesseler, Hoe Chang, Matthew Charette, Peter Croot, Ken Downing, Russel Frew, Mark Gall, Mark Hadfield, Julie Hall, Greg Jameson, Julie LaRoche, Malcolm Liddicoat, Roger Ling, Maria T. Maldonado, R. Michael McKay, Scott Nodder, Stu Pickmere, Rick Pridmore, Steve Rintoul, Karl Safi, Philip Sutton, Robert Strzepek, Kim Tanneberger, Suzanne Turner, Anya Waite, and John Zeldis. *Nature*, Vol. **407**, 12 October 2000, pages 695-702.
- "Importance of stirring in the development of an iron-fertilized phytoplankton bloom", Edward R. Abraham, Cliff S. Law, Philip W. Boyd, Samantha J. Lavender, Maria T. Maldonado, and Andrew R. Bowie. *Nature*, Vol. **407**, 12 October 2000, pages 727-730.
- "Effect of iron supply on Southern Ocean CO_2 uptake and implications for glacial atmospheric CO_2", A.J. Watson, D.C.E. Bakker, A.J. Ridgwell, P.W. Boyd, and C.S. Law. *Nature*, Vol. **407**, 12 October 2000, pages 730-733.
- "Glacial/interglacial variations in atmospheric carbon dioxide", Daniel M. Sigman and Edward A. Boyle. *Nature*, Vol. **407**, 19 October 2000, pages 859-869.
- "Iron-stimulated changes in 13C fractionation and export by equatorial Pacific phytoplankton: Toward a paleo growth rate proxy", R.R. Bidigare, K.L. Hanson, K.O. Buesseler, S.G. Wakeham, K.H. Freeman, R.D. Pancost, F.J. Millero, P. Steinbeg, B.N. Pop, M. Latasa, M.R. Landry, and E.A. Laws. *Paleoceanography*, **14**, 1999, pages 589-595.